

# Negative Nominal Interest Rates Can Worsen Liquidity Traps \*

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## Abstract

Can central banks use negative nominal interest rates to overcome the adverse effects of the zero lower bound? I show that negative rates are likely to be counterproductive in an expectations-driven liquidity trap. In a liquidity trap, firms expect low demand and cut prices, which leads the central bank to reduce nominal rates to their lower bound. If the resulting decline in real rates is not enough to stabilize demand, then the pessimism of price setters is fulfilled. Theoretically, the effect of a negative nominal rate is non-monotonic: a marginally negative rate is not enough to escape the liquidity trap, but allows for more pessimistic expectations and deflation, while a sufficiently negative rate eliminates the trap altogether. However, plausible estimates of the cost and benefits of price adjustments in the U.S. suggest that negative rates are contractionary in a liquidity trap, even at  $-100$  percent.

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# 1 Introduction

Since 2015, central banks in countries representing nearly a quarter of world GDP have set short-run nominal rates below zero (Fray [11]). But does negative interest rate policy (NIRP) actually improve aggregate outcomes? I study the efficacy of NIRP in a sticky-price New Keynesian model with two steady-state equilibria, one that is “intended” with high output and inflation and one that represents an expectations-driven liquidity trap with low output and deflation, ala Benhabib, Schmitt-Grohe, and Uribe [3],[4].<sup>1</sup> Theoretically, NIRP is contractionary unless rates can be set below a threshold, at which point the liquidity trap is eliminated. Quantitatively, any plausible NIRP makes the liquidity trap worse when the model is calibrated to the United States.

The liquidity trap arises because firms expect low demand, which leads them to reduce prices. An active central bank responds by reducing nominal rates to their lower bound, which is not enough to stabilize demand, thereby affirming the expectations of price setters. Locally, the liquidity trap equilibrium is “neo-Fisherian”: reducing the nominal rate below zero simply allows for price-setters to conceive of lower demand and more deflation, to which they respond by cutting their prices more severely than when the nominal rate was zero. However, a sufficiently bold NIRP eliminates the liquidity trap by pushing deflation below the limit of how quickly firms are willing to cut prices, even with the most pessimistic of expectations. Since the effect of NIRP is theoretically non-monotone, I use the model to calculate the threshold at which NIRP eliminates the liquidity trap, as well as the magnitude of output and inflation losses generated by a NIRP above this threshold.

The threshold at which NIRP eliminates the liquidity trap depends on the limiting rate of deflation chosen by firms when they expect the deepest possible recession, which they set by equating the cost of reducing prices to the present value of additional revenues generated from doing so. Price adjustment costs directly affect the willingness of firms to deflate, while the benefit from deflation depends on how elastic demand is to a firm’s relative price and the rate at which firms discount future revenues. Empirically, the limit on deflation is calculated using the slope of the Phillips Curve and the natural rate of interest. Estimates of these parameters for the United States suggest that the threshold NIRP required to eliminate the liquidity trap is below  $-100\%$  per quarter.<sup>2</sup> In short, NIRP cannot eliminate the liquidity trap.

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<sup>1</sup>There is also a continuum of non-stationary equilibria that converge to the liquidity trap steady state. I will focus on the steady state, since eliminating it will ensure that the intended equilibrium is unique.

<sup>2</sup>The model is in continuous time, so the fact that  $i$  is substantially negative means that

Although the model predicts that NIRP is contractionary, the negative effects on output and inflation are small for marginally negative nominal rates. In the baseline calibration, output in the liquidity trap is reduced by 0.13% when the nominal rate is allowed to fall to  $-0.5\%$  annually, as it did in the euro zone in September 2019 (ECB [1]). However, the further negative rates are set, the more contractionary the effect. For example, in a May 2019 interview, David Andolfatto of the Federal Reserve Bank of St. Louis suggests that nominal rates could fall to  $-10\%$ , a cost of storing cash consistent with Colombian drug kingpin Pablo Escobar’s annual currency losses from buried money degrading underground (Andolfatto [2]). This “Escobar Bound” of  $-10\%$  generates quarterly output losses of 1.09% in the baseline calibration and is above the NIRP required to eliminate the liquidity trap, even in calibrations with a higher natural rate or flatter Phillips Curve (which raise the threshold at which NIRP eliminates the liquidity trap).

In the standard sticky-price New Keynesian model, estimates of the slope of the Phillips Curve and the natural rate of interest are enough to calculate the effect of NIRP, but extensions of the model can both raise and lower the NIRP required to eliminate liquidity traps. Section 4.4 shows that NIRP becomes less able to eliminate liquidity traps if prices are more flexible in a deep recession, while section 5.1 shows that real wage rigidities have the opposite effect on the efficacy of NIRP. More fundamental changes to the model can even reverse the local comparative statics of the NIRP. In section 5.2, I introduce NIRP to Michailat and Saez’s [17] “Wealth in the Utility” model, which assumes that households discount future consumption heavily, but still wish to save because wealth directly increases their future utility. In that case, NIRP is locally expansionary, but is unable to eliminate the liquidity trap. More generally, these theoretical models highlight that the effect of NIRP depends on the shape of the Phillips Curve in a deep recession, which is difficult to establish empirically, so the effects of NIRP are inherently uncertain.

This paper contributes to a growing literature on NIRP. While many papers focus on the institutional arrangements necessary to set negative nominal rates, I take the ability of central banks to do so as given and focus instead on the effects predicted by a workhorse macroeconomic model. Similarly, Buiter and Panigirtzoglou [5] study a New Keynesian model with liquidity trap equilibria and the possibility of negative nominal rates. They consider the effects of this policy on inflation in an endowment economy and find that the negative interest rate policy *always* eliminates the liquidity trap equilibrium, whereas the

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the usual approximation of  $e^i - 1 \approx i$  is poor. A discrete-time version of the model would truly require a rate below  $-100\%$ , but is less elegant.

model with endogenous output highlights the non-monotone effect of NIRP. Rognlie [19] also studies the effect of negative interest rates in a New Keynesian model but assumes that prices are completely rigid. This assumption corresponds to a version of the present model in which the expectations-driven liquidity trap does not exist in the first place because price adjustment costs are infinite. Finally, Eggertsson, Juelsrud, and Wold [10] and Eggertsson, et al. [9] consider new models in which negative nominal rates become contractionary beyond some effective lower bound because banks eventually pass their losses from holding negative yielding debt to customers in the form of higher interest rates. Their model suggests that the effective lower bound is well above the threshold that I calculate in the absence of a banking sector.

Other related papers do not consider NIRP explicitly, but highlight the neo-Fisherian effects of nominal rates in liquidity trap equilibria. Schmitt-Grohe and Uribe [20] show that an interest rate rule that jumps to a higher nominal peg during the liquidity trap is expansionary, which is the mirror image of my finding that NIRP is locally contractionary. Importantly, increasing the nominal rate will not eliminate the liquidity trap, whereas a sufficiently negative rate could, in theory. Cuba-Borda and Singh [7] find a similar effect of raising nominal rates in a model with both expectations-driven liquidity traps and secular stagnation. To my knowledge, mine is the first paper to highlight the non-monotone effect of negative nominal rates in the liquidity trap, or to calculate whether a sufficiently negative rate could eliminate the liquidity trap.

Section 2 outlines the model and solves for steady-state equilibria. Section 3 performs qualitative comparative statics, while section 4 uses estimates of parameter values to calculate the required NIRP to eliminate liquidity traps. Section 5 then examines changes to the model that allow small negative interest rates to be expansionary, either by changing the local comparative statics or by eliminating the liquidity trap for larger negative rates.

## 2 Model

The model features Rotemberg price adjustment costs in continuous time. The economy comprises a continuum of consumer-producer households, each of which sells a differentiated good indexed by  $j$ . The household chooses sequences,

$$\{(c_{\ell,t})_{\ell \in [0,1]}, n_t, \pi_t, p_{j,t}, N_t\}_{t=0}^{\infty}$$

to maximize:

$$\int_0^\infty e^{-\delta t} \left[ \log \left[ \int_0^1 c_{\ell,t}^{\frac{\epsilon-1}{\epsilon}} d\ell \right]^{\frac{\epsilon}{\epsilon-1}} - \Psi \frac{\nu}{1+\nu} n_t^{\frac{1+\nu}{\nu}} - 0.5\gamma\pi_t^2 \right] dt, \quad (1)$$

subject to the constraints

$$\dot{b}_t + \int_0^1 p_{\ell,t} c_{\ell,t} d\ell = i_t b_t + W_t n_t + Profit_{j,t} \quad (2)$$

$$Profit_{j,t} = p_{j,t} y_{j,t}^d(p_{j,t}) - W_t N_t \quad (3)$$

$$\dot{p}_{j,t} = \pi_t p_{j,t} \quad (4)$$

$$N_t \geq y_{j,t}^d(p_{j,t}) \quad (5)$$

where the nominal wages and interest rates are taken as given.

The wage is determined by labor market clearing, while the nominal interest rate is set by policy according to a Taylor Rule with two key features. First, the nominal rate responds more than one for one to changes to inflation. Second, the nominal rate is bound below by  $-\zeta$ . That is,

$$i_t = \max\{\delta + \phi\pi_t, -\zeta\}, \quad (6)$$

with  $\phi > 1$  and  $\zeta \geq 0$ .

## 2.1 Equilibrium System

Two equations govern the dynamics of output and inflation:

$$\frac{\dot{Y}_t}{Y_t} = \max\{(\phi - 1)\pi_t, -\zeta - \delta - \pi_t\}, \quad (7)$$

$$\dot{\pi}_t = \delta\pi_t - \frac{\epsilon}{\gamma} \Psi Y_t^{\frac{1+\nu}{\nu}} + \frac{\epsilon - 1}{\gamma}. \quad (8)$$

These equations determine two steady-state equilibria as well as the dynamics around each steady state. I will focus on the steady-states, but it is well known that there is a continuum of non-stationary equilibria that converge to the liquidity trap steady state. Eliminating the liquidity trap steady state will therefore eliminate these non-stationary equilibria as well.

## 2.2 Steady State Equilibria

There is always at least one steady-state equilibrium, which is labelled as the “intended” equilibrium with  $\pi^I = 0$  and  $y^I = \left( \frac{\epsilon-1}{\Psi\epsilon} \right)^{\frac{\nu}{1+\nu}}$ . However, there may

also be an expectations-driven liquidity trap steady-state in which the nominal rate is equal to  $-\zeta$  and inflation and output are given by

$$\pi^Z = -(\zeta + \delta), \quad (9)$$

$$Y^Z = \left[ \frac{\epsilon - 1}{\Psi\epsilon} - \frac{\delta\gamma(\zeta + \delta)}{\Psi\epsilon} \right]^{\frac{\nu}{1+\nu}}. \quad (10)$$

This steady state apparently exists under the condition that the constant inflation locus intercepts below  $-(\zeta + \delta)$ . The analysis is only interesting if this assumption holds, which amounts to the following restriction on parameters:

$$-\frac{\epsilon - 1}{\gamma\delta} < -(\zeta + \delta). \quad (11)$$

### 3 Comparative Statics and Discussion

The effects of introducing a negative nominal rate are shown in Figure (1). The blue, dashed curve corresponds to combinations of output and inflation such that inflation is constant while the dotted red lines correspond to constant output and depend on  $\zeta$ . Starting with  $\zeta = 0$ , the model has two steady-states, labelled  $(y^I, \pi^I)$  and  $(y_{\zeta=0}^Z, \pi_{\zeta=0}^Z)$ , the latter corresponding to the expectations-driven liquidity trap. Note that the intercept of the constant inflation locus is drawn strictly below  $-\delta$ , which means that setting  $\zeta$  to a small positive number shifts the constant-output locus previously associated with  $\pi = -\delta$  to  $\pi = -(\delta + \zeta^-)$ , which now intersects the constant inflation locus at point  $(y_{\zeta^-}^Z, \pi_{\zeta^-}^Z)$  (with no effect on the intended equilibrium). Therefore, a negative interest rate policy makes the liquidity trap equilibrium worse, at least locally.

Now consider what happens with a substantially negative nominal rate by setting  $\zeta$  to

$$\zeta^+ > \zeta^* \geq \frac{\epsilon - 1 - \gamma\delta^2}{\gamma\delta}, \quad (12)$$

which is illustrated with the third and lowest steady-state Euler Equation. This is below the intercept of the constant inflation locus. The three parameters,  $\gamma$ ,  $\epsilon$  and  $\delta$ , govern how negative nominal rates must be in order to eliminate the liquidity trap and do so in an intuitive way. The cost of changing prices is  $\gamma$ . The larger it is the less deflation can be consistent with profit maximization and therefore the easier it is to eliminate the deflationary liquidity trap equilibrium. The second is the elasticity of substitution between goods,  $\epsilon$ , which determines the marginal benefit of cutting prices when everybody else is expected to do so. The larger is this parameter the more sensitive is demand to

the producer’s relative price and the stronger her incentive to deflate when she expects others to do the same. Finally,  $\delta$  is used to discount future revenues generated from a current price adjustment. The smaller is this parameter the more firms value the future effects of their current inflation decision.

## 4 Quantitative Evaluation

It is useful to set some parameter values in order to ask how negative the nominal bound would need to be in order to eliminate the liquidity trap, as well as the effects of negative interest rates that are not large enough to do so.

### 4.1 Baseline Calibration

The model frequency is quarterly and  $\delta = 0.002$ , corresponding to a 0.8% annual real rate in the intended equilibrium. This is consistent with recent estimates of the natural rate using the models of Laubach and Williams [15] and Holston, Laubach, and Williams [14], but is much lower than historical averages.<sup>3</sup> The Frisch elasticity of labor supply is set to  $\nu = 0.75$  in the baseline calibration, which is the value recommended by Chetty, et al. [6], while the disutility parameter  $\Psi$  is set to normalize output in the intended steady-state to one.

Economically, the adjustment cost and elasticity of substitution parameters are pivotal for the limits of deflation in the liquidity trap, yet they enter jointly in determining the intercept of the constant inflation locus. My strategy for choosing  $\frac{\epsilon-1}{\gamma}$  is to assume that historical estimates of the Phillips Curve have used data near the intended equilibrium. As presented in Glover [13], the stochastic discrete-time version of this model would have the following Phillips Curve, after it is log-linearized around the intended steady-state:<sup>4</sup>

$$\pi_t = e^{-\delta} \mathbb{E}_t \pi_{t+1} + \left( \frac{\epsilon}{\gamma} \right) \left( \frac{1+\nu}{\nu} \right) \Psi(y^I)^{\frac{1+\nu}{\nu}} \left( \log y_t - \log y^I \right). \quad (13)$$

Assuming that labor supply is chosen to equate the marginal rate of substitution between consumption and labor to the real wage gives

$$\Psi(y^I)^{\frac{1+\nu}{\nu}} = \frac{w}{P} = \frac{\epsilon - 1}{\epsilon}, \quad (14)$$

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<sup>3</sup>The Federal Reserve of New York maintains up-to-date estimates of the natural rate using these models at the address <https://www.newyorkfed.org/research/policy/rstar>.

<sup>4</sup>The model in Glover [13] has heterogenous labor supply and lower bounds on real wages, but gives the Phillips Curve in equation 13 if parameters are set so that only one labor type enters production and the real minimum wage is zero.

which means that the theoretical slope of the Phillips Curve is  $\kappa \equiv \frac{1+\nu}{\nu} \times \frac{\epsilon-1}{\gamma}$ .

Mavroeidis, Plagborg-Møller, and Stock [16] review estimates of the slope of the Phillips Curve and report a range of 0.005 to 0.08 and their own estimate of 0.018. Using the bottom of their range of estimates in Equation 12 gives an estimate of how negative the nominal rate must fall in order to eliminate liquidity traps:

$$-\zeta^* = -\left(\frac{0.005}{0.002} \times \frac{0.75}{1.75} - 0.002\right) = -107\%. \quad (15)$$

Therefore, eliminating the liquidity trap equilibrium requires the lower bound on nominal rates below  $-107\%$  per quarter. Since the model is continuous and the rate is far from 0, this is a poor approximation of the total loss over a quarter, which is  $e^{-1.07} - 1 = -65.7\%$ . However, the discrete version of the model achieves the most deflation possible when  $\zeta = \frac{1}{2e^{-\delta}} = 0.501$ , which generates deflation of  $-25\%$  per quarter. This is above the amount required to eliminate the liquidity trap given the above parameters. Therefore, both the continuous-time and discrete versions of the model suggest that it is impossible to eliminate the liquidity trap through NIRP.

For values of  $\zeta$  that are not sufficiently large to eliminate the liquidity trap, output and inflation fall monotonically. Figure 2 shows liquidity trap output and inflation as a function of the lower bound on nominal rates, using the above parameters. The decline in inflation is one-for-one, while the decline in output is concave, so that a small negative interest rate has little effect on output, but a large one can make the liquidity trap recession much more severe. This suggests that the NIRP observed in many countries since 2014 would be mildly contractionary if those economies were stuck in a liquidity trap.

## 4.2 The Natural Rate of Interest

The baseline calibration used a natural rate of 0.2% per quarter, which is consistent with recent estimates of the natural rate, but substantially lower than historical averages. How does a negative lower bound on nominal rates interact with a low natural rate? In the context of this model, a lower natural rate requires an increasingly negative nominal interest rate in order to eliminate the liquidity trap. Figure 4 plots the relationship of  $\zeta^*$  as  $\delta$  varies from 0.001 to 0.01, fixing the slope of the Phillips Curve at 0.005. The convexity of this curve highlights the heightened difficulty of eliminating the liquidity trap through negative nominal rates in a world of low natural rates.

### 4.3 The Slope of the Phillips Curve

The steeper is the Phillips Curve in output, the more negative the nominal rate must be in order to eliminate the liquidity trap. The logic is that a higher value of  $\kappa$  in this model must be due to either a larger elasticity of substitution or a smaller adjustment cost parameter. The baseline calibration uses the lowest value reported in Mavroeidis, Plagborg-Moller, and Stock [16] and still requires a nominal rate below  $-100\%$ , so any further increase will just require a more extreme NIRP.

However, much of the data used to estimate  $\kappa$  is from a period when the natural rate was much higher, so it is useful to consider how  $\kappa$  affects  $\zeta^*$  for a larger natural rate. Figure 3 plots the NIRP required to eliminate liquidity traps as a function of  $\kappa$  when  $\delta = 0.01$ . Even with a high natural rate and  $\kappa = 0.005$ , the nominal rate must fall to  $-22.4\%$  per quarter in order to eliminate the liquidity trap and the value of  $\kappa$  at which  $\zeta^*$  reaches  $100\%$  is  $0.0236$ , which is well within the range of estimates reported by Mavroeidis, Plagborg-Moller, and Stock [16]. This suggests that NIRP will remain contractionary in a liquidity trap, even if the natural rate returns to its historical average.

### 4.4 Labor Cost of Price Adjustment

Thus far,  $\gamma$  has been a constant parameter. Another possibility is that price adjustments require labor, which must be paid the prevailing wage. This creates a state-contingent cost of price adjustment, which can be captured by assuming that

$$\gamma_t = \Psi Y_t^{\frac{1+\nu}{\nu}}. \quad (16)$$

This change in interpretation of adjustment costs fundamentally changes the ability of negative interest rates to eliminate liquidity traps, since the Phillips Curve is now given by

$$\dot{\pi}_t = \delta\pi_t - \epsilon + \epsilon Y_t^{-\frac{1+\nu}{\nu}}. \quad (17)$$

The constant-inflation locus is now drawn in Figure 5 as a concave curve that asymptotes to  $-\infty$  as  $y \rightarrow 0$ . There is no longer a sufficiently negative lower bound on nominal rates to eliminate the self-fulfilling expectations of deflation, since the cost of price adjustment endogenously declines with output, via wages. This exercise highlights that uncertainty about price flexibility in the liquidity trap may be important, even if one prefers combinations of parameters that generate an extremely flat Phillips Curve near the intended steady state.

## 5 When Is a Small NIRP Expansionary?

The model is simple enough to highlight two ways that a smaller negative interest rate could eliminate the liquidity trap. One possibility is to disconnect the intercept of the constant inflation locus from the estimated slope, such that the intercept is higher on the inflation axis, thereby requiring a smaller downward shift in the IS curve to eliminate the liquidity trap. The other is to fundamentally change the IS curve so that NIRP is locally expansionary in the liquidity trap equilibrium.

### 5.1 Wages Rigidities

In the basic model, firms who expect competitors to deflate due to low demand find it optimal to do so, partly because they expect their real wage bill to be low in such a setting. This is because lower output requires less labor, and therefore real wages are low in equilibrium. The presence of wage rigidities tends to flatten the constant inflation locus and raise the intercept (some studies that discuss this include Daly and Hobijn [8], Schmitt-Grohe and Uribe [20], and Glover [12], [13]). I now consider a version of the model with a hard lower bound on the real wage, based on the average real minimum wage in the U.S.<sup>5</sup>

Following Glover [13], the model with a real minimum wage of  $\omega$  gives rise to the following Phillips Curve

$$\dot{\pi}_t = \delta\pi_t - \frac{\epsilon}{\gamma} \max \left\{ \omega, \Psi Y_t^{\frac{1+\nu}{\nu}} \right\} + \frac{\epsilon - 1}{\gamma}. \quad (18)$$

The resulting zero-inflation locus is drawn in Figure 6, in which there are two changes of note. First, the intercept has been raised by  $\frac{\epsilon}{\gamma}\omega$ . Second, the curve has become flat for output below

$$\underline{Y} = \left( \frac{\omega}{\Psi} \right)^{\frac{\nu}{1+\nu}}. \quad (19)$$

Quantitatively,  $\omega$  can be calibrated using the minimum wage relative to average wages in the United States. The OECD reports this ratio to be 25%

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<sup>5</sup>The minimum wage is modeled as a real wage floor rather than a nominal. A nominal wage floor would eliminate the deflationary liquidity trap equilibrium, regardless of whether a NIRP was employed. A more complex model in which liquidity traps are associated with inflation below a positive target rather than outright deflation is required to study a nominal minimum wage.

in 2017 [18] and the model gives a real wage in the intended equilibrium of  $\frac{\epsilon-1}{\epsilon}$ . I therefore set  $\omega = 0.25\left(\frac{\epsilon-1}{\epsilon}\right)$ . Using  $\kappa = 0.005$ ,  $\nu = 0.75$ , and  $\epsilon = 10$  gives  $\gamma = 4200$ . The new NIRP required to eliminate the liquidity trap is

$$\zeta^* = \frac{10 - 1}{0.002 \times 4200} - \frac{10}{0.002 \times 4200} \times 0.25 \times \frac{9}{10} - 0.02 = 80.2\%. \quad (20)$$

Therefore, accounting for the effect of minimum wages on the intercept of the Phillips Curve suggests that a negative lower bound on interest rates of 80.2% per quarter is enough to eliminate the liquidity trap. This is still much more negative than what has been seen in reality or discussed by proponents of NIRP, but demonstrates that wage rigidities make NIRP more effective.<sup>6</sup>

## 5.2 Wealth in the Utility

Michaillat and Saez [17] enrich the goods block of the New Keynesian model so that the constant-output locus is upward sloping in output when interest rates are at their lower bound. Furthermore, they calibrate the model so that the intercept of the liquidity trap constant output locus is below the intercept of the constant inflation locus and the slope is steeper. Their differential equation for inflation is unchanged, but their expression for output growth is now

$$\frac{\dot{Y}_t}{Y_t} = \max\{(\phi - 1)\pi_t, -(\zeta + \delta) + \mu Y_t - \pi_t\}, \quad (21)$$

where  $\mu > 0$  is a parameter that arises from households directly valuing wealth in their utility functions.

There are now two ways that a liquidity trap equilibrium could occur. One possibility is that  $\delta$  and  $\mu$  are both small, which gives a liquidity trap that is essentially the same as in the basic model. Another has a large value of both  $\delta$  and  $\mu$ , so that the liquidity trap intersection occurs with the constant-output locus cutting the constant-inflation locus from below, as shown in Figure 7. This is the case considered by Michaillat and Saez, who calibrate values of  $\delta$  and  $\mu$  to match laboratory estimates of time preference and the natural rate of interest. That is, they set  $\delta = 0.43$  on an annual basis and target a natural rate of 0.02. Essentially, their calibration says that people are much less patient regarding consumption than is typically assumed, but that they save nonetheless because they directly value the levels of their wealth.

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<sup>6</sup>This is an extreme example where the zero-inflation locus is unchanged above  $\underline{y}$ , but completely flat below. If the wage rigidity flattened the curve in addition to increasing the intercept, then there would be an additional output loss for values of  $\zeta$  that are insufficient to eliminate the liquidity trap.

In the Michaillat and Saez parameterization, there is no longer a neo-Fisherian effect of negative nominal rates in the liquidity trap, nor is the effect non-monotone. Reducing the nominal rate to a negative value always pushes the constant output locus downward, without changing the slope, and is therefore expansionary. In fact, the liquidity trap can occur at an intersection with positive inflation and higher than intended output, if a sufficiently negative rate is set.

Therefore, setting a negative lower bound on nominal rates may be globally expansionary, if savings motives are driven by wealth-in-the utility and if the natural rate largely reflects direct utility over wealth by households who heavily discount future consumption. Of course, even this result would be reversed in the constant-inflation locus became steeper as output falls towards zero, as in the model from Section 4.4.

## 6 Conclusion

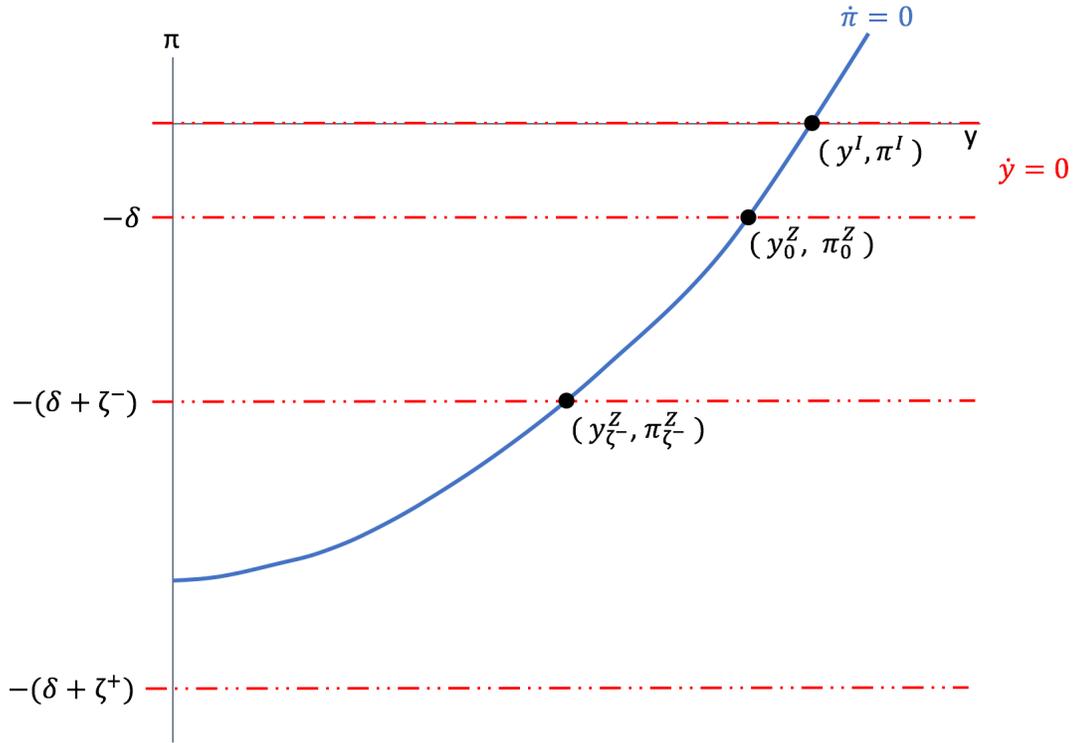
Negative nominal interest rates were thought impossible until very recently. The fact that countries now issue debt with negative yields has raised the question of whether a negative interest rate should be part of the monetary policy toolbox. While there is substantial uncertainty about how low negative rates could be set, it is a moot point if doing so is unlikely to stabilize the economy in the first place. This paper has shown that negative interest rates are likely to make things worse in an economy plagued by liquidity traps, given available evidence about the Phillips Curve and natural rate of interest.

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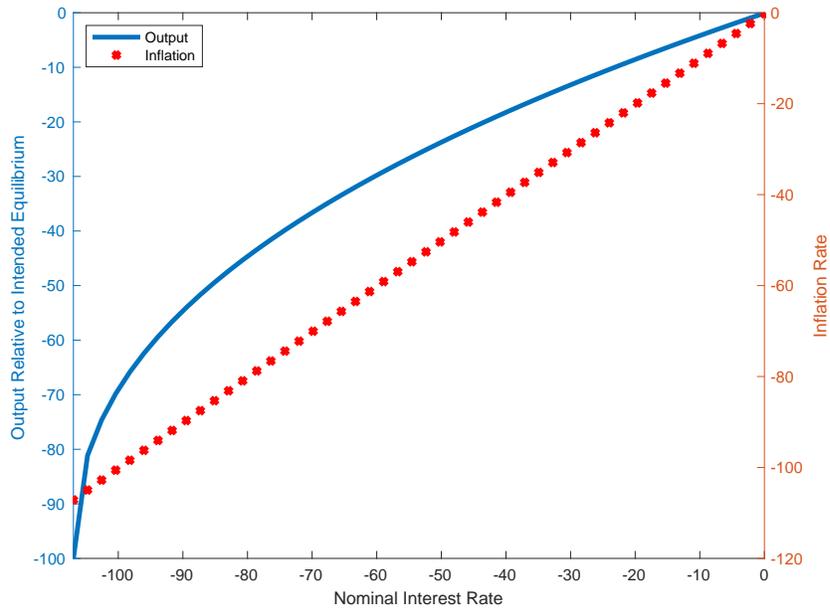
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Figure 1: Effects of Varying Negative Nominal Rate



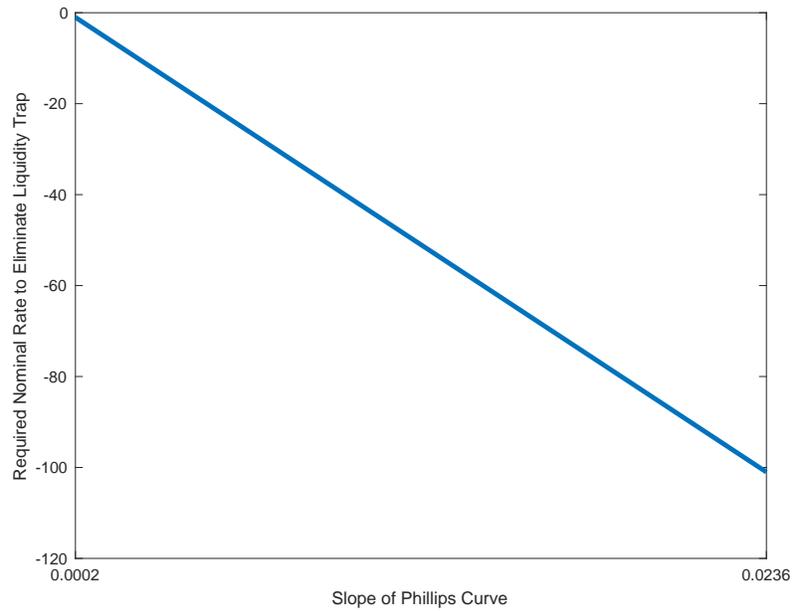
Notes: Plot shows constant-inflation and constant-output loci from theoretical sticky-price New Keynesian model. Intersections of these loci determine steady-state equilibria for different values of the lower bound on nominal interest rates,  $\zeta$ . The intended equilibrium has constant-output locus at  $\pi = 0$  and has steady state  $(y^I, \pi^I)$  that is independent of  $\zeta$ . The liquidity trap steady-states,  $(y^Z, \pi^Z)$ , are generated by constant-output curves drawn at  $\pi = -(\delta + \zeta)$  and are indexed by  $\zeta$ , whenever they exist.

Figure 2: Liquidity Trap Equilibria Vary With NIRP



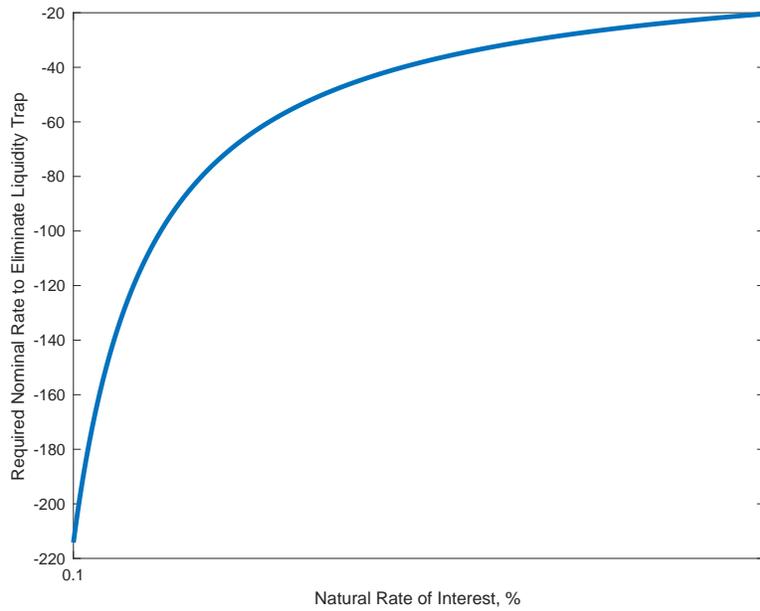
Notes: Solid blue line (left axis) plots output losses in liquidity trap, relative to intended equilibrium, for negative lower bounds on nominal interest rates between  $-107\%$  and  $0\%$ . Dotted red line (right axis) plots inflation in the liquidity trap.

Figure 3: Required NIRP For Different Phillips Curve Slopes



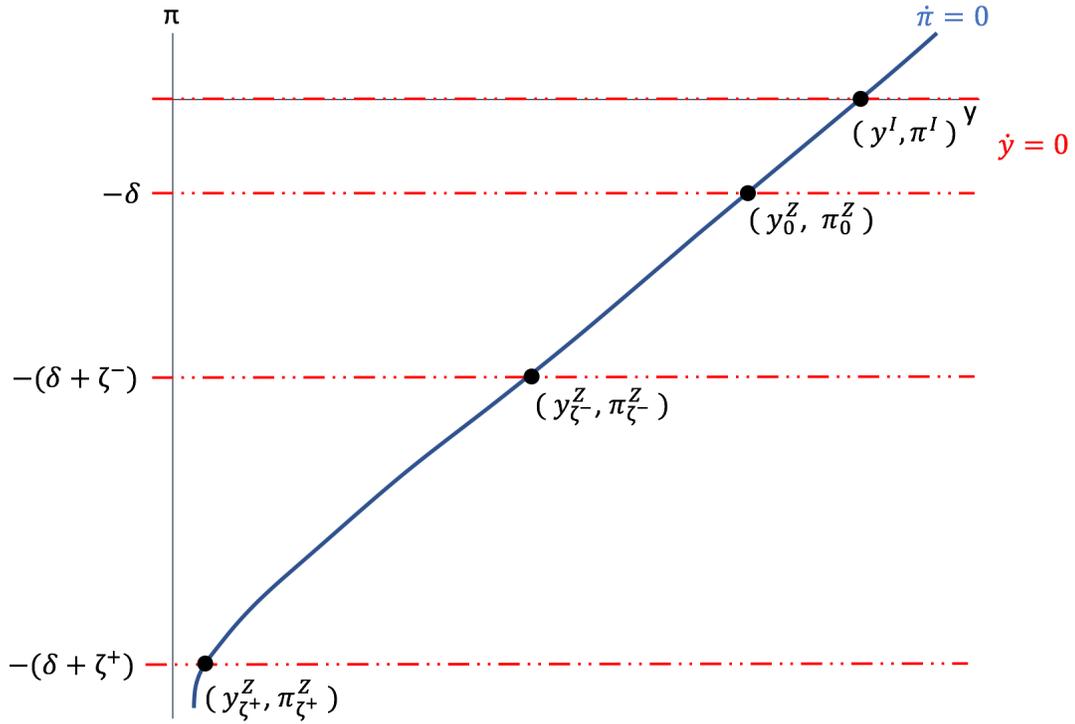
Notes: Plot shows the lower bound on nominal interest rates required to eliminate the liquidity trap when the natural rate is 4% annually and the slope of the Phillips Curve varies between 0.0002, which is the smallest values for which a liquidity trap exists, and 0.0236, at which point a lower bound of  $-100\%$  is required to eliminate the liquidity trap.

Figure 4: Required NIRP For Different Natural Rates



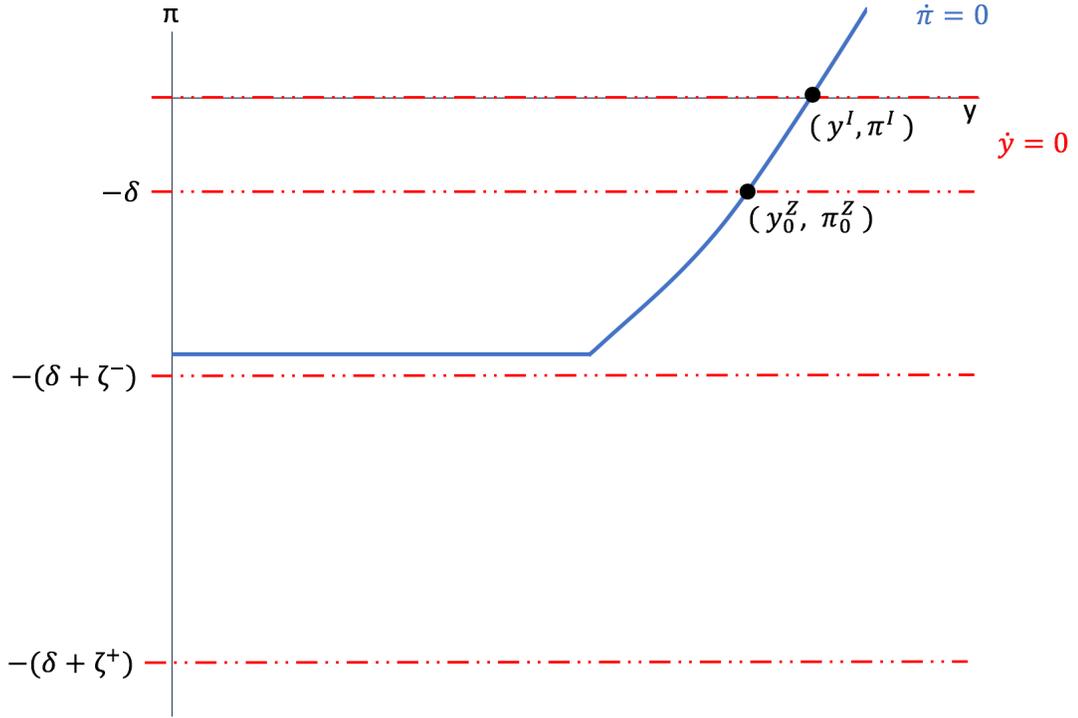
Notes: Plot shows the lower bound on nominal interest rates required to eliminate the liquidity trap when the slope of the Phillips Curve is 0.005 and the natural rate of interest varies between 0.1% and 1% per quarter.

Figure 5: NIRP When Labor Used For Price Adjustment



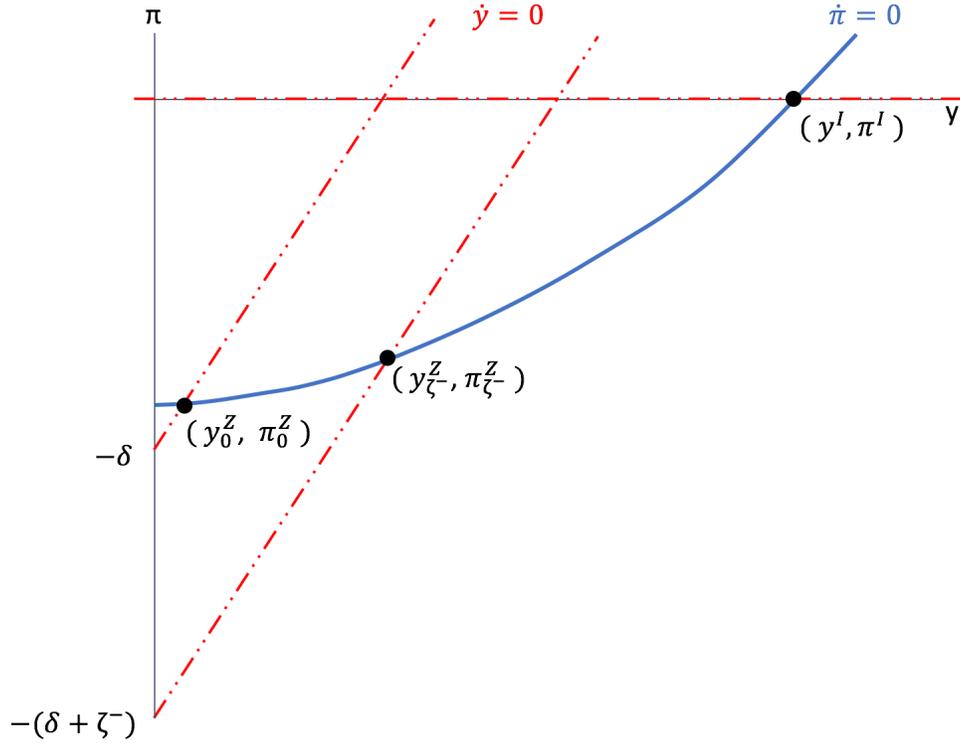
Notes: Plot shows constant-inflation and constant-output loci from theoretical sticky-price New Keynesian model when the cost of adjusting prices is measured in real wages. Intersections of these loci determine steady-state equilibria for different values of the lower bound on nominal interest rates,  $\zeta$ . The intended equilibrium has constant-output locus at  $\pi = 0$  and has steady state  $(y^I, \pi^I)$  that is independent of  $\zeta$ . The liquidity trap steady-states,  $(y^Z, \pi^Z)$ , are generated by constant-output curves drawn at  $\pi = -(\delta + \zeta)$  and are indexed by  $\zeta$ , whenever they exist.

Figure 6: NIRP In Model With Minimum Wage



Notes: Plot shows constant-inflation and constant-output loci from theoretical sticky-price New Keynesian model with real minimum wage. Intersections of these loci determine steady-state equilibria for different values of the lower bound on nominal interest rates,  $\zeta$ . The intended equilibrium has constant-output locus at  $\pi = 0$  and has steady state  $(y^I, \pi^I)$  that is independent of  $\zeta$ . The liquidity trap steady-states,  $(y^Z, \pi^Z)$ , are generated by constant-output curves drawn at  $\pi = -(\delta + \zeta)$  and are indexed by  $\zeta$ , whenever they exist.

Figure 7: NIRP In Model With Wealth In Utility



Notes: Plot shows constant-inflation and constant-output loci from theoretical sticky-price New Keynesian model with wealth in the utility and constant-output loci that intersect the constant-inflation locus from below. Intersections of these loci determine steady-state equilibria for different values of the lower bound on nominal interest rates,  $\zeta$ . The intended equilibrium has constant-output locus at  $\pi = 0$  and has steady state  $(y^I, \pi^I)$  that is independent of  $\zeta$ . The liquidity trap steady-states,  $(y^Z, \pi^Z)$ , are generated by constant-output curves drawn at  $\pi = -(\delta + \zeta)$  and are indexed by  $\zeta$ , whenever they exist.